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Review

Organic waste treatment for power production and energy supply

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Sudan is endowed with abundant solar, wind, hydro, and biomass resources. Like many tropical countries, sudan has ample biomass resources that can be efficiently exploited in a manner that is both profitable and sustainable. Fuel-wood farming offers cost-effective and environmentally friendly energy solutions for Sudan, with the added benefit of providing sustainable livelihoods in rural areas. Biogas from biomass appears to have potential as an alternative energy in Sudan, which is potentially rich in biomass resources. This is an overview of some salient points and perspectives of biomass technology in Sudan. This current literature is reviewed regarding the ecological, social, cultural and economic impacts of biomass technology. This article provides an overview of biomass energy activities and highlights future plans concerning optimum technical and economical utilisation of biomass energy available in Sudan.

Keywords: Sudan, biomass energy, biofuels, biogas, bioheat, utilisation and development

INTRODUCTION

Energy is an essential factor in development since it stimulates, and supports economic growth and development. Fossil fuels, especially oil and natural gas, are finite in extent, and should be regarded as depleting assets, and efforts are oriented to search for new sources of energy. The clamour all over the world for the need to conserve energy and the environment has intensified as traditional energy resources continue to dwindle whilst the environment becomes increasingly degraded. Biomass energy supply in Sudan contributed 87% of total energy supply since 1980's. The basic form of biomass comes mainly from firewood, charcoal and crop residues. Out of total fuel wood and charcoal supplies 92% was consumed in household sector with most of firewood consumption in the rural areas (Omer, 2005). Alternatively energy sources can potentially help fulfil the acute energy demand and sustain economic growth in many regions of the world. Bioenergy is beginning to gain importance in the global fight to prevent climate change. The scope for exploiting organic waste as a source of energy is not limited to direct incineration or burning refuse-derived fuels. Biogas, biofuels and woody biomass are other forms of energy sources that can be derived from organic waste materials. These renewable energy sources have significant potential in the fight against climate change.

Therefore as a renewable energy source, biomass (especially fuelwood) seems interesting because its share of the total energy production at 87% is high and the techniques for converting it to useful energy are easy. On the other hand, biomass may, however, see greatly expanded use in response to the environmental problems caused by fossil fuel use in the country. Agriculture is the backbone of economic and social development in Sudan. Biomass resources play a significant role in energy supply in Sudan as shown in Tables 1 - 2. Cooking is largely done with firewood 45% and charcoal 30% (BOS, 2003). Hence, 75% of total energy per annum, representing roughly 3 million metric tons of forest reserves, and agricultural residues comes mainly from cotton stalks, groundnut shells and bagasse with estimates of more than 15 million metric tons. Also, considerable amount of non-woody biomass available is animal dung, estimated 17 million tons as shown in Table 3. Water hyacinth and aquatic weeds are estimated 9000 and 3000 tons per annum respectively.

Bioenergy

Bioenergy is energy from the sun stored in materials of biological origin. This includes plant matter and animal waste, known as biomass. Plants store solar energy was-

Table 1. Sources of biomass energy available in Sudan 10^6 tons of equivalent (TOE) (Omer, 2005).

Item	Source	10^6 TOE
1.	Natural, and cultivated forests	2.90
2.	Agricultural residues	6.20
3.	Animal wastes	1.05
4.	Water hyacinth	3.16
Total		13.31

Table 2. Biomass energy consumption in Sudan 10^3 Tons of equivalent (TOE) (Omer, 2005).

Item	Sector	10^3 TOE	(%)
1.	Residential	4549	92.0
2.	Industrial	169	3.4
3.	Others*	209	4.6
Total		4927	100.0

*Others are commercial, constructions, and Quranic schools.

Table 3. Biomass energy potential from animal dung in different states of Sudan (Omer, 2005).

Item	States	Animal dung available (10^3 Tons)	Energy (TOE)
1.	Northern states	102.4	1543
2.	Eastern states	1222.9	18431
3.	Khartoum state	104.3	1572
4.	Central states	4223.7	63658
5.	Darfur states	5062.5	36301
6.	Kordofan states	2596.9	79140
7.	Southern states	4545.2	68505
Total		17857.9	269150

through photosynthesis in cellulose and lignin, whereas animals store energy as fats. When burned, these sugars break down and release energy exothermically, releasing carbon dioxide, heat and steam. The by-products of this reaction can be captured and manipulated to create power, commonly called bioenergy. Biomass is considered renewable because the carbon is taken out of the atmosphere and replenished more quickly than the millions of years required for fossil fuels to form. The use of biofuels to replace fossil fuels contributes to a reduction in the overall release of carbon dioxide into the atmosphere and hence helps to tackle global warming. The range of waste treatment technologies that are tailored to produce bioenergy is growing. There are a number of key areas of bioenergy from wastes including (but not limited to) biogas, biofuels and bioheat. When considering using bioenergy, it is important to take into account the overall emission of carbon in the process of electricity production (Omer, 1996).

Biomass CHP

Combined heat and power (CHP) installations are quite common in greenhouses, which grow high-energy, input crops (e.g., salad vegetables, pot plants, etc.). Scientific assumptions for a short-term energy strategy suggest that the most economically efficient way to replace the thermal plants is to modernise existing power plants to increase their energy efficiency and to improve their environmental performance. However, utilisation of wind power and the conversion of gas-fired CHP plants to biomass would significantly reduce Sudan's dependence on imported fossil fuels. Although a lack of generating capacity is forecast in the long-term, utilisation of the existing renewable energy potential and the huge possibilities for increasing energy efficiency are sufficient to meet future energy demands in Sudan in the short-term.

A total shift towards a sustainable energy system is a complex and long process, but is one that can be achieved within a period of about 20 years. Implemen-tation will require initial investment, long-term national strategies and action plans. However, the changes will have a number of benefits including: a more stable energy supply than at present and major improvement in the environmental performance of the energy sector, and certain social benefits. A vision used a methodology and calculations based on computer modelling that utilised: Data from existing governmental programmes; Potential renewable energy sources and energy efficiency improvements; Assumptions for future economy growth; Information from studies and surveys on the recent situation in the energy sector.

In addition to realising the economic potential identified by the National Energy Savings Programme, a long-term effort leading to a 3% reduction in specific electricity demand per year after 2020 is proposed. This will require: further improvements in building codes, and continued information on energy efficiency.

The environmental NGOs in Sudan are urging the government to adopt sustainable development of the energy sector by: Diversifying of primary energy sources to increase the contribution of renewable and local energy resources in the total energy balance and implementing measures for energy efficiency increase at the demand side and in the energy transformation sector.

The price of natural gas is set by a number of market and regulatory factors that include: Supply and demand balance and market fundamentals, weather, pipeline availability and deliverability, storage inventory, new supply sources, prices of other energy alternatives and regulatory issues and uncertainty.

Classic management approaches to risk are well documented and used in many industries. This includes the following four broad approaches to risk:

1). Avoidance includes not performing an activity that could carry risk. Avoidance may seem the answer to all risks, but avoiding risks also means losing out on potential gain.

Table 4. Purchasing strategies using hedges.

Strategy	Description
Index	Fuel is purchased month-by-month at a first of the month index price
Forward physical purchase	Monthly fuel is purchased in advance for an averaged fixed price
Cap	A fixed price for fuel is set, but ‘put’ contracts are purchased to guarantee that when future market prices for fuel settle below the fixed cost, the monthly price is adjusted downward towards the tower index price
Collar	A series of ‘put’ and ‘call’ contracts are purchased to guarantee that monthly prices for fossil fuel will be contained within a defined price range regardless of market conditions
Hybrid	Where a percentage of each month’s fuel needs are purchased at a fixed price, and the reminder purchased at an index price
Winter strip	Fuel purchased at a fixed price from November through March, and at an index price all other months

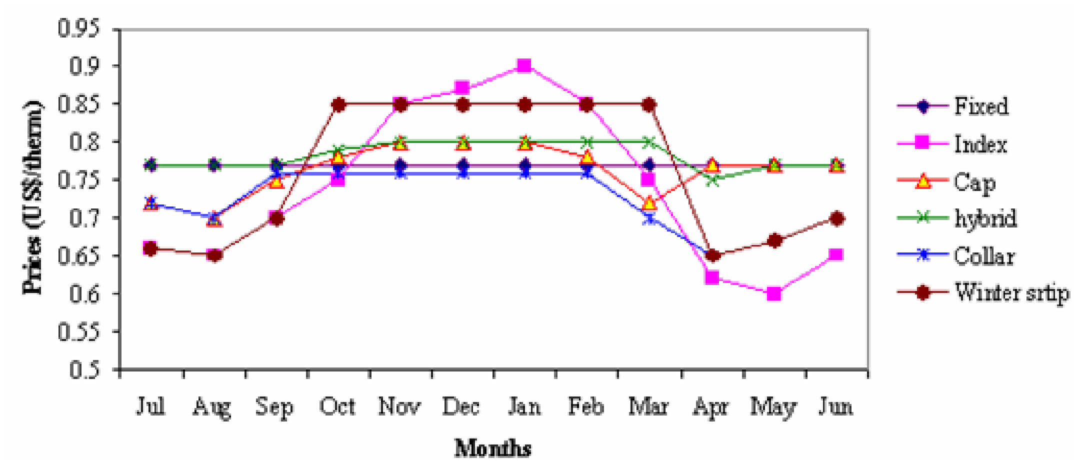


Figure 1. Purchasing strategies using hedges.

2). Mitigation/reduction involves methods that reduce the severity of potential loss.
3). Retention/acceptance involves accepting the loss when it occurs.
4). Risk retention is a viable strategy for small risks. All risks that are not avoided or transferred are retained by default. Transfer means causing another party to accept the risk, typically by contract.

Risk management

Financial hedges (such as futures and options) are contractual vehicles that convey rights and obligations to buy or sell a commodity at a specified price. Possible purchasing strategies using hedges are summarised in Table 4. These financial derivations are a method of reducing price risk with a relatively modest transaction price. Over the past 10 years the use of financial hedges has grown dramatically. Figure 1 illustrates various hypothetical reduction strategies and the resulting average fuel price. The basic concept is to utilise existing financial tools to guard against conditions that will negatively affect the operating budget. Basic hedges include:

Swap contract: A bilateral agreement with a party that agree to guarantee a ‘fixed’ price.

Future contract: A financial tool that limits upside price exposure.

Options contract: A financial tool that can limit upside and downside price exposure (‘puts’ are a hedge against falling prices, and ‘calls’ are a hedge against rising prices).

Politicians at the local and national level have evaluated sustainability as an important issue facing the communities. The future will have leaders who develop sustainable solid waste programmes that further improve the community to achieve the following: 1). Reduce the generation of solid waste by establishing policies that encourage manufacturer to reduce packaging material volumes. 2). Reuse/recycle/recover the pre-collection waste. 3). Promote the development of ‘green’ local secondary

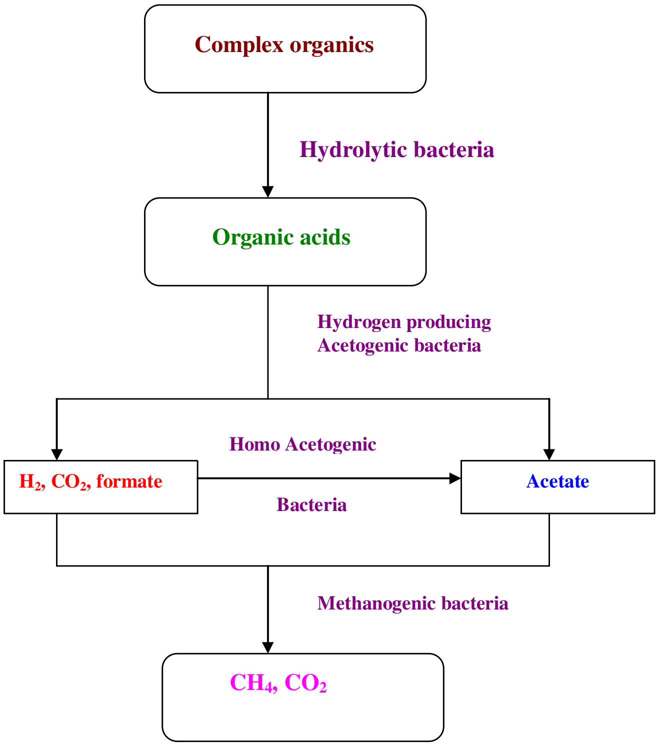


Figure 2. Biogas production process (Omer, 2003).

material manufacturing facilities through implementation of tax credits and incentives. 4). Thermally treat the remaining waste by either incineration or gasification and produce renewable 'green power' or 'green energy'. 5). Landfill the discarded/unusable material.

The demand for energy continues to outstrip supply and necessitates the development of renewable energy option. Effective low-carbon and renewable energy policies need to encourage millions of building owners, Biogas is a generic term for gases generated from the decomposition of organic material. As the material breaks down, methane (CH_4) is produced as shown in Figure 2. developers, and construction companies to invest. To do this, incentives need to be reliable, predictable and sufficiently valuable and long-term in nature to encourage sustained investment. An effective strategy needs to be developed that would address these characteristics and provide the support needed to stimulate the market to create a level playing field electricity producing projects: a). First, polices should be based on a long-term meaningful price for carbon. Currently there is no carbon price for heating or cooling, as existing mechanisms do not apply to this market. b). Secondly, policies should support innovation. A heating and cooling strategy could encourage innovation in technologies, building design and urban planning, controls and metering. It should also drive innovation in financing and commercial structures. c). Thirdly, it should encourage behaviour change. A strategy that encourages low-carbon and renewables could through small-scale technologies give the public a clear opportunity to become directly involved a solution to climate change and change consumers' view surrounding these technologies.

Biogas

Sources that generate biogas are numerous and varied. These include landfill sites, wastewater treatment plants and anaerobic digesters.

Biogas typically comprises of 50-75% methane and carbon dioxide along with other minor gases. It is the methane that is used for the generation of electricity or use as a fuel for transportation. Biogas is produced by anaerobic digestion where complex carbon molecules in organic material are broken down into simpler structures including CH_4 and CO_2. Biogas can be produced from a variety of biodegradable waste feedstocks including sewage sludge, biodegradable waste and mixed municipal waste or as a natural process of decomposition in landfills. Typically different variants of anaerobic digesters need to be used to treat each different feedstock optimally. The absorption potential of agricultural soils could contribute significantly to fulfilling the goal to reduce carbon dioxide emissions. Compost as a soil improver is primarily intended to give organic matter to soils, thereby resulting in many benefits of improving levels of organic matter in soil such as: improved structure and workability, improved water retention and locking up carbon in soils, which will be retained in a comparatively long time frame. Many possible side effect of compost application can also be considered including: A reduction in the use of pesticides (might imply avoiding emissions for their production); improved workability (might lead to less consumption of fuels) and the displacement of chemical fertilizers (implies avoidance of greenhouse gases and energy uptake related to their production).

Bacteria form biogas during anaerobic fermentation of organic matters. The degradation is very complex process and requires certain environmental conditions as well as different bacteria population. The complete anaerobic fermentation process is briefly described below as shown in Table 5. The organic matter was biodegradable to produce biogas and the variation show a normal methanogene bacteria activity and good working biological process as shown in Figures 3 - 4.

Factors to be considered in economic analysis

The introduction of biogas technology on wide scale has implications for macro planning such as the allocation of government investment and effects on the balance of payments. Factors that determine the rate of acceptance of biogas plants, such as credit facilities and technical backup services, are likely to have to be planned as part of general macro-policy, as do the allocation of research and pollution control can optimise the promotion and development of agricultural and animal husbandry in rural

Table 5. Anaerobic degradation of organic matter (Omer, 2003).

Level	Substance	Molecule	Bacteria
Initial	Manure, vegetable, wastes	Cellulose, proteins	Cellulolytic,proteolytic
Intermediate	Acids, gases, oxidised, inorganic salts	CH_3COOH, $CHOOH$, SO_4, CO_2, H_2, NO_3	Acidogenic, hydrogenic, sulphate reducing
Final	Biogas, reduced inorganic compounds	CH_4, CO_2, H_2S, NH_3, NH_4	Methane formers

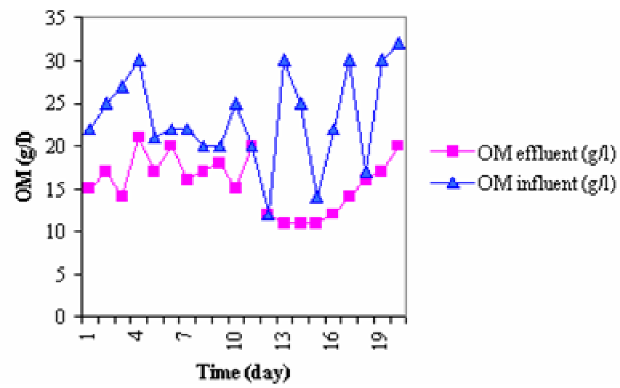


Figure 3. Organic matters before and after treatment in digester.

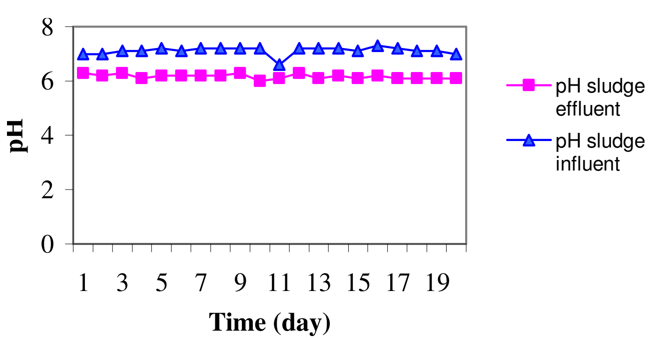


Figure 4. pH sludge before and after treatment in the digester.

areas.

Economic factors are: Interest on loan; Current/future cost of alternative fuels; Current/future cost of chemical fertiliser; Current/future cost of construction materials; Saving of foreign currency; Current/ future labour cost; Inflation rate; Costs of transport of feeding materials and effluents

Social factors are: Employment created; Better lighting: more educational/cultural activities; Less time consumed for fetching firewood and for cooking; Improved facilities in villages; thus less migration to cities; Less expense for buying alternative fuels; More time for additional income earning activities. Technical factors are: Construction, maintenance and repairs of biogas plants; Availability of materials and land required; Suitability of local materials

Ecological/health factors are: Improved health; Forest conservation (positive or negative); Environment pollution abatement; Improvement in yields of agricultural products Growth, modernisation and urbanisation in many states of Sudan have created both energy supply shortages and a growing source of free fuel: biogas. The use of biogas has been proven and is ready to be deployed in Sudan. The technology is available, it is economically feasible and it is reliable. An additional benefit of using these gases as a fuel source is minimisation of the environ-mental impacts that result from gas venting or flaring. The burning of such gases release air-borne pollutants, which can also enter groundwater sources and pollute farm-lands. The optimum range in Table 6 is for ambient temperatures during hot seasons of Sudan tropical climates. The potential gas volumes produced from wastes vary depending on many factors, and can be expressed based in head count.

Bioheat

Bioenergy is a growing source of power that is playing an ever-increasing role in the provision of electricity. The potential contribution of the waste industry to bioenergy is huge and has the ability to account for a source of large amount of total bioenergy production in Sudan. Woody biomass is usually converted into power through combustion or gasification. Biomass can be specially grown in the case of energy crops. Waste wood makes up a significant proportion of a variety of municipal, commercial and industrial waste streams. It is common practice to dispose of this waste wood in landfill where it slowly degraded and takes up valuable void space. This wood is a good source of energy and is an alternative to energy crops.

Gasification is based on the formation of a fuel gas (mostly CO and H_2) by partially oxidising raw solid fuel at high temperatures in the presence of steam or air. The technology can use wood chips, groundnut shells, sugar cane bagasse, and other similar fuels to generate capacities from 3 kW to 100 kW. Three types of gasifier designs (Figure 5) have been developed to make use of the diversity of fuel inputs and to meet the requirements of the product gas output (degree of cleanliness, composition, heating value, etc.). The requirements of gas for various purposes, and a comparison between biogas;

Table 6. Optimum conditions for biogas production (Omer, 2003).

Parameter	Optimum value
Temperature ºC	30-35
pH	6.8-7.5
Carbon/Nitrogen ratio	20-30
Solid content (%)	7-9
Retention time (days)	20-40

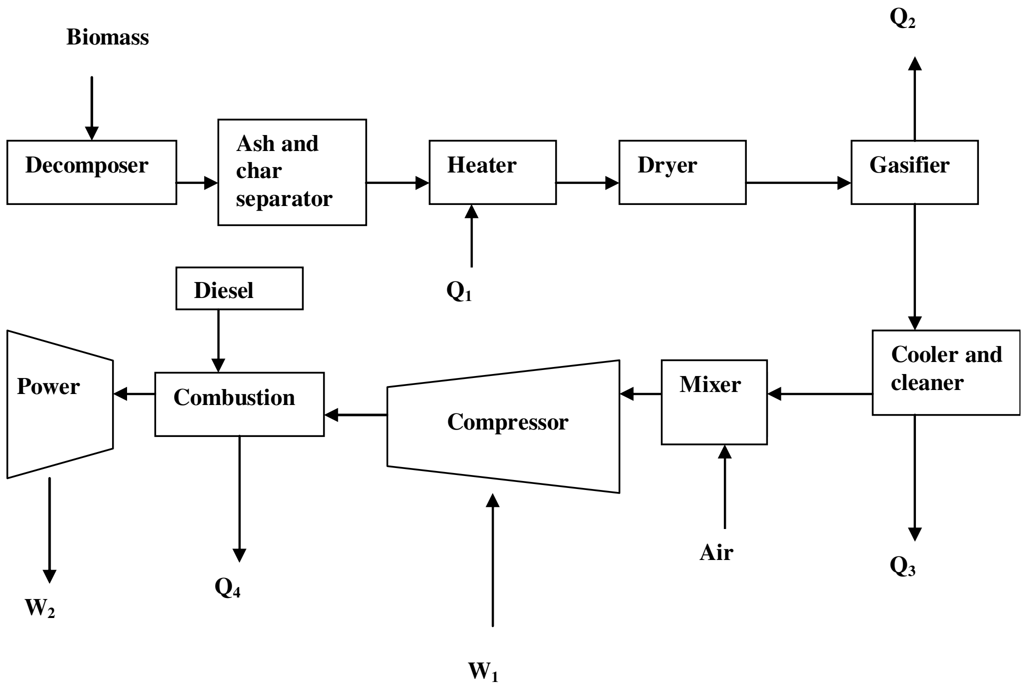


Figure 5. Advanced biomass power with diesel engine.

and various commercial fuels in terms of calorific value, and thermal efficiency are presented in Table 7.

Biomass is a raw material that has been utilised for a wide variety of tasks since the dawn of civilisation. Important as a supply of fuel in the third world, biomass was also the first raw material in the production of textiles. The gasification of the carbon char with steam can make a large difference to the surface area of the carbon. The corresponding stream gasification reactions are endothermic and demonstrate how the steam reacts with the carbon char (Bacaoui et al., 1998).

$$H_2O(g) + C_x(s) \longrightarrow H_2\,(g) + CO\,(g) + C_{x-1}\,(s) \quad (1)$$

$$CO(g) + H_2O(g) \longrightarrow CO_2\,(g) + H_2\,(g) \quad (2)$$

$$CO_2(g) + C_x(s) \longrightarrow 2CO\,(g) + C_{x-1}\,(s) \quad (3)$$

Agricultural wastes are abundantly available globally and can be converted to energy and useful chemicals by a number of microorganisms. The success of promoting any technology depends on careful planning, management, implementation, training and monitoring. Main features of gasification project are: Networking and institutional development/strengthening; Promotion and extension; Construction of demonstration projects; Research and development, and training and monitoring.

Waste policy in context

In terms of solid waste management policy, Sudan has changed drastically in the past ten years from a mass production and mass consumption society to ‘material-cycle society’. In addition to national legislation, municipalities are legally obliged to develop a plan for handling the municipal solid waste (MSW) generated in administrative areas. Such plans contain: Estimates of future waste volume; Measures to reduce waste; Measures to encourage source separation; A framework for solid waste disposal and the construction and management of solid waste management facilities. Landfilling is in the least referred tier of the hierarchy of waste management

Table 7. Comparison of various fuels (Omer, 2003).

Fuel	Calorific value (kcal)	Burning mode	Thermal efficiency (%)
Electricity, kWh	880	Hot plate	70
Coal gas, kg	4004	Standard burner	60
Biogas, m^3	5373	‘’ ‘’	60
Kerosene, l	9122	Pressure stove	50
Charcoal, kg	6930	Open stove	28
Soft coke, kg	6292	‘’ ‘’	28
Firewood, kg	3821	‘’ ‘’	17
Cow dung, kg	2092	‘’ ‘’	11

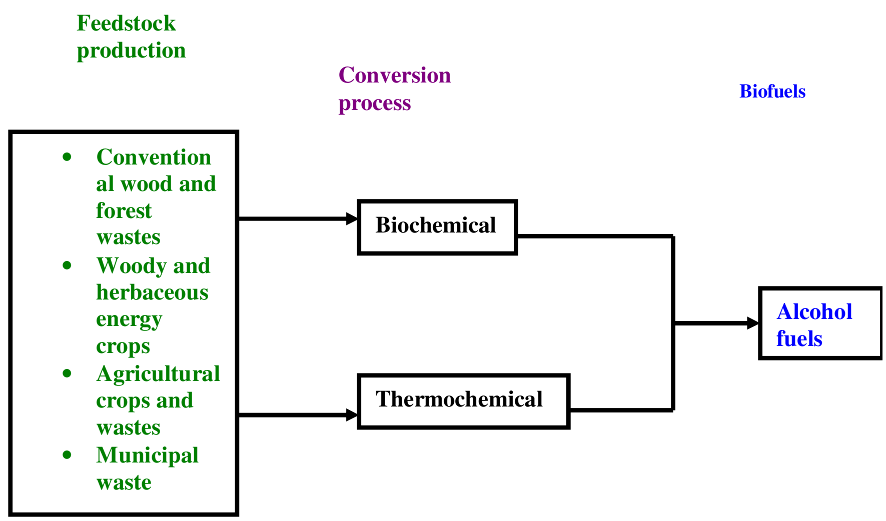


Figure 6. Biofuel pathways for renewable alcohol fuels.

options: Waste minimisation, reuse and recycling, incineration with energy recovery, and optimised final disposal.

Environmental impacts

The key elements are as follows: Construction impacts, atmospheric emissions, noise, water quality, landscape, visual impacts, socio economics, ecological impacts, traffic, solid waste disposal and cultural heritage.

Alternative fuels were defined as methanol, ethanol, natural gas, propane, hydrogen, coal-derived liquids, biological material and electricity. The fuel pathways currently under development for alcohol fuels are shown in Figure 6. The production of agricultural biomass and its exploitation for energy purposes can contribute to alleviate several problems, such as the dependence on import of energy products, the production of food surpluses, the pollution provoked by the use of fossil fuels, the abandonment of land by farmers and the connected urbanisation. Biomass is not at the moment competitive with mineral oil, but, taking into account also indirect cost costs and giving a value to the aforementioned advantages, public authorities at national and international level can spur its production and use by incentives of different nature (NFC, 1999). The biomass directly produced by cultivation can be transformed by different processes into gaseous, liquid or solid fuels (Table 8). The whole process of production of methyl or ethyl esters (biodiesel) is summarised in Figure 7.

Energy from agricultural biomass

The main advantages are related to energy, agriculture and environment problems, which are foreseeable both at Sudan level and at worldwide level and can be summarised as follows: Reduction of dependence on import of energy and related products; Reduction of environmental impact of energy production (greenhouse effect, air pollution, waste degradation); Substitution of food crops and reduction of food surpluses and of related economic burdens; Utilisation of marginal lands and of set aside lands and reduction of related socio-economic and environmental problems (soil erosion, urbanisation, landscape deterioration, etc.); Development of new know-how and

Table 8. Biomass conversions to energy Rossi et al. (1990).

Feedstock	Crops	Conversion process	End product
Wood-cellulosic biomass	Short rotation forest (poplar, willow), plant species (sorghum, mischantus, etc.), fibre-crops (cynara, kenaf, etc.)	Direct combustion Gasification Pyrolysis	Heat Methane Hydrogen Oil
Vegetable oils	Oleaginous crops (rapeseed, soybean, sunflower, etc.)	Direct combustion Esterification	Heat Biodiesel
Sugar/starch	Cereals, root and tuber crops, grape, topinambour, etc.	Fermentation	Ethanol

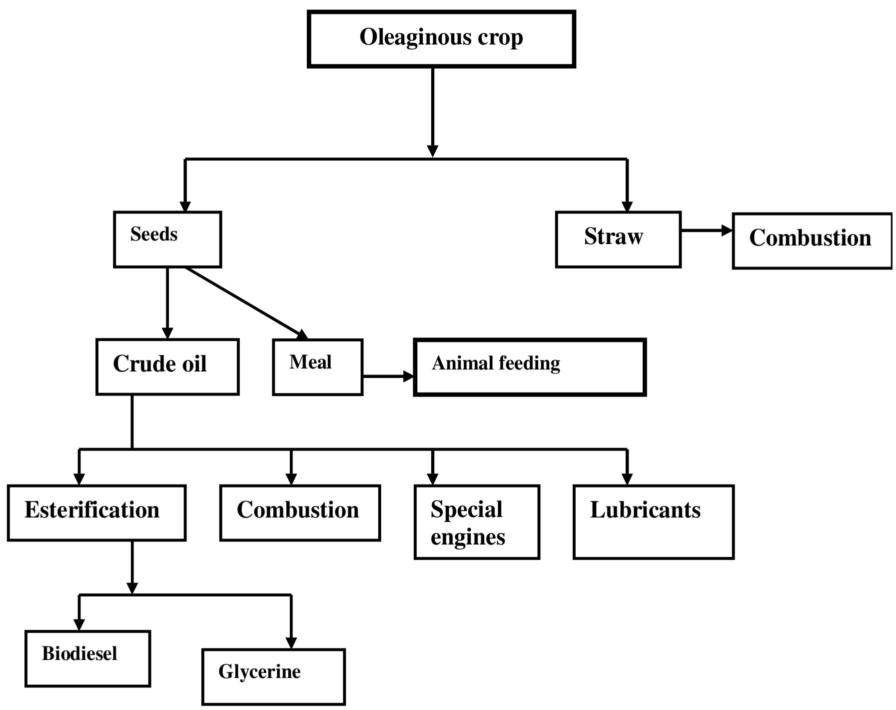


Figure 7. Flow chart of biodiesel production.

production of technological innovation.

A study by Rossi et al. (1990) individuated on the basis of botanical, genetical, physiological, biochemical, agronomical and technological knowledge reported in literature some 150 species potentially exploitable divided as reported in Table 9.

Role of chemical engineering

Turning to chemical engineering and the experience of the chemical process industry represents a wakening up but does not lead to an immediate solution to the problems. The traditional techniques are not very kind to biological products, which are controlled by difficulty and unique physico-chemical properties such as low mechanical, thermal and chemical stabilities. There is the question of selectivity. The fermentation broths resulting from microbial growth contain a bewildering mixture of many compounds closely related to the product of interests. By the standards of the process streams in chemical industry, fermenter is highly impure and extremely dilutes aqueous systems (Table 10).

The disadvantages of the fermentation media are as the following: Mechanically fragile, temperature sensitive, rapidly deteriorating quality, harmful if escaping into the environment, corrosive (acids, chlorides, etc.), and troublesome (solids, theological, etc.), and expensive. Thus, pilot plants for scale-up work must be flexible. In general, they should contain suitably interconnected equipment for: fermentation, primary separation, cell disruption fractionalises and clarifications, purification by means of high-resolution techniques and concentration and dry.

Table 9. Plant species potentially exploitable for production of agricultural biomass for energy or industrial utilisations Rossi et al. (1990).

Groups of plants	Number of species
Plants cultivated for food purposes that can be reconverted to new uses	9
Plants cultivated in the past, but not in culture any more	46
Plants cultivated in other world areas	46
Wild species, both indigenous and exotic	47
Total	148
Plant product	Number of species
Biomass	8
Sugars and polysaccharides	38
Cellulose	17
Hydrocarbons	3
Polymeric hydrocarbons	5
Gums and resins	12
Tannins and phenolic compounds	3
Waxes	7
Vegetable oils	38
Total	131

Table 10. Typical product concentrations exiting fermenters Rossi et al. (1990).

Product	Concentration (kg/m^3)
Ethanol	70-120
Organic acids (e.g., citric)	40-100
Vitamin B12	0.02
Interferon	50-70
Single-cell protein	30-50
Antibiotics (e.g., Penicillin G)	10-30
Enzyme protein (e.g., protease)	2-5

Fluidised bed drying

An important consideration for operators of wastewater treatment plants is how to handle the disposal of the residual sludge in a reliable, sustainable, legal and economical way. The benefits of drying sludge can be seen in two main treatment options: Use of the dewatered sludge as a fertiliser or in fertiliser blends and Incineration with energy recovery.

Use as a fertiliser takes advantage of the high organic content 40 - 70% of the dewatered sludge and its high levels of phosphorous and other nutrients. However, there are a number of concerns about this route including: The chemical composition of the sludge (e.g., heavy metals, hormones and other pharmaceutical residues); Pathogen risk (e.g., salmonella, *Escherichia coli*, prionic proteins, etc.); Potential accumulation of heavy metals and other chemicals in the soil.

Sludge can be applied as a fertiliser in three forms: liquid sludge, wet cake blended into compost, and dried granules.

The advantages of energy recovery sludge include: The use of dewatered sludge is a ‘sink’ for pollutants such as heavy metals, toxic organic compounds and pharmaceutical residues. Thus, offering a potential disposal route for these substances provided the combustion plant has adequate flue gas cleaning, the potential, under certain circumstances, to utilise the inorganic residue from sludge incineration (incinerator ash), such as in cement or gravel, the high calorific value (similar to lignite) of dewatered sludge and the use of dewatered sludge as a carbon dioxide neutral substitute for primary fuels such as oil, gas and coal.

Sugar cane biomass

Sudan has 640 MW of installed electricity capacity and the country’s total electricity generation is 3000 GWh. Its main generating facility is the 280 MW Roseires dam located on the Blue Nile river basin. The facility suffers from drought induced low water levels, which often cause

Table 11. Annual sugarcane bagasse available in Sudan (10^3 tonnes) (Omer, 1996).

Factory	Design capacity	Yearly bagasse production 1995-2001
Kenana	300	266
El Genaid	60	53
New Halfa	75	65
Sennar	100	58
Asalaia	100	60
Total	635	502

its output to fall to 100 MW. Sudan is one the largest sugar-producing countries worldwide. It has five operational sugar factories an additional two under construction. Four of the existing factories (New Halfa, El Genaid, Asalaia and Sennar sugar factories) are owned by the state and managed by the Sudan Sugar Company. The fifth is Kenana Sugar Company, which is a privately owned factory. The original design of each of the sugar factories under construction includes a cogeneration plant. There are plans to move into high-pressure advanced cogeneration systems to diversify the country's power supplies. Residuals from the sugar cane industry repre-sent by far the most important source of current and potential biomass resources in Sudan. The sugar industry in Sudan goes back fifty years and Sudan has been one of the world's leading sugar producers. Sugar cane plantations cover one-fifth of the arable land in Sudan. In addition, to raw sugar, Sudanese enterprises produce and utilise many valuable cane co-products for feed, food, ener-gy and fibre. At present, there are 5 sugar factories as illustrated in Table 11.

Sugar cane bagasse and sugar cane trash already provide a significant amount of biomass for electricity production, but the potential is much higher with advanced cogeneration technologies. Most sugar factories in Sudan, as elsewhere in the developing world, can produce about 15 - 30 kWh per tonne of cane. If all factories were fitted with biomass gasifier-combined cycle systems, 400 - 800 kWh of electricity could be produced per tonne of cane, enough to satisfy all of Sudan's current electricity demand. Some of the sugar plants are near electric grids (Kenana, El Genaid and Sennar) and others have their own grids.

In Sudan there are no alcohol distilleries. The three factories were closed with Islamic Laws in 1983. The current circumstances suggest that Sudan should consider expanding production for use as transportation fuel, but this option has not yet been pursued. The alcohol was used for a variety of applications, mainly for medical purposes and rum production. Blending with gasoline would also have direct environmental advantages by substituting for lead as an octane enhancer (WB, 1990).

There is an unmistakable link between energy and sustainable human development. Energy is not an end in itself, but an essential tool to facilitate social and economic activities. Thus, the lack of available energy services correlates closely with many challenges of sustainable development, such as poverty alleviation, the advancement of women, protection of the environment, and jobs creation. Emphasis on institution-building and enhanced policy dialogue is necessary to create the social, economic, and politically enabling conditions for a transition to a more sustainable future. On the other hand, biomass energy technologies are a promising option, with a potentially large impact for Sudan as with other developing countries, where the current levels of energy services are low. Biomass accounts for about one third of all energy in developing countries as a whole, and nearly 96% in some of least developed countries. The convention on Biological Diversity set conservation of biodiversity on the world agenda. Gaps in knowledge need to be addressed for actions to be effective and sustainable. Gaps include: species diversity, microorganisms and their ecological roles, ecological and geographical status of species, human capacity to access and forecast bioecological degradation. Requirements for global inventories call for worldwide collaboration. Criteria for setting priorities need to be formulated and agreed. Global inventorying needs a collaborative international effort, perhaps under the aegis of the Convention on Biological Diversity. The recently formulated global taxonomy initiatives are a step in the right direction.

Bioenergy potential

For efficient use of bioenergy resources, it is essential to take account of the intrinsic energy potential. Despite the availability of basic statistics, many differences have been observed between the previous assessments of bioenergy potential (FAO, 1999; and NFA, 1994). These were probably due to different assumptions or incomplete estimations of the availability, accessibility and use of by products. The biomass sources have been used through: Anaerobic digestion of municipal wastes and sewage, direct combustion of forestry and wood processing residues, direct combustion in the case of main dry crop residues and anaerobic digestion of moist residues of agricultural crops and animal wastes.

Wood is very important raw material used by a number of industries. Its excessive utilizations as a fuel results in soil erosion, degradation of the land, reduced agricultural productivity and potentially serious ecological damage. Hence, minimizations of fuelwood use seem to be essential.

Utilisation of more efficient stoves and improvement of insulation using locally available materials in buildings are also effective measures to increase efficiency. Biogas or commercial fuels may be thought of as possible substitutes for fuelwood. In rural areas of Sudan, liquefied petroleum gases (LPGs) are strong candidate to replace firewood. Indeed, increased in LPG utilisation over the last decade has been one of the main reasons that have lead to the deceleration of the diffusion of biogas tech-nology into rural areas.

Biomass gasification is a technology that transforms solid biomass into syngas (hydrogen and carbon monoxide mixtures produced from carbonaceous fuel). Current use of biomass, which stands at about 87% of the total energy supply in Sudan, is primarily used in combustion for immediate use. Small-scale gasification for combined heat and power (CHP), also called embedded generation. Many villages and mini-grids can be served by biomass power generation in the size range from 1 kWe to 5 MWe. Biomass fuels are characterised by high and variable moisture content, low ash content, low density, and fibrous structure. In comparison with other fuels, they are regarded as of low quality despite low ash content and very low Sulphur content.

Even though community digesters for a whole village appear to be economically more attractive, family type designs should also be studied. Moreover, detailed realistic economic and cost-benefit comparisons with other alternatives will help in determining the level of incentives that could be produced by the government for the construction of digesters. The energy possibilities of Industrial and municipality wastes should be evaluated, especially in the big cities. Combined heat and power systems could be designed to make use of these wastes as fuel. The possibilities of using waste heat in district heating systems could be also of interest in industrial regions.

Environmental issues of biomass

Climate change is a growing concern around the world, and stakeholders are aggressively seeking energy sources and technologies that can mitigate the impact of global warming. This global concern is manifest in the 1997 Kyoto Protocol, which imposes an imperative on developed nations to identify feasible options by the next Conference of the Parties to the Convention (COP) meeting later in 2001. Possible actions range from basic increases in energy efficiency and conservation, to sophisticated methods of carbon sequestration to capture the most common greenhouse gases (GHGs) emission (CO_2) On the other hand, renewable energies have always been identified as a prime source of clean energies that emit little or no net GHGs into the atmosphere. Among the renewable energy sources, biomass is important for Sudan due to its share of the total energy production which at 87% is high and the technique for converting it to useful energy is easy.

Forest ecosystems cause effects on the balance of carbon mainly by the assimilation of CO_2 by the above ground biomass of the forest vegetation. The annual emissions of greenhouse gases from fossil fuel combustion and land use change are approximately 33 x 10^5 and 38 x 10^5 tonnes respectively. Vegetation and in particular forests, can be managed to sequester carbon. Management options have been identified to conserve and sequester up to 90 Pg C in the forest sector in the next century, through global afforestation (Haripriye, 2000; and Hall, 1998). This option may become a necessity (as recommended at the Framework Convention on Climate Change meeting held in Kyoto), but a preventative approach could be taken, reducing total GHGs emissions by substituting biomass for fossil fuels in electricity production.

Simply sequestering carbon in new forests is problematic because trees cease sequestering once they reach maturity, and as available land is used up the cost of further afforestation will grow. Indeed the cost of reducing the build-up of GHGs in the atmosphere is already lower for fossil fuel substitution than for sequestration, since fast growing energy crops are more efficient at carbon removal, and because revenue is generated by the scale of electricity. Some biomass fuel cycles can also provide the additional benefits of enhanced carbon storage. The relative merits of sequestration versus fossil fuel substitution are still debated. The flow of carbon during the life cycle of the biomass should determine whether it is better left standing, used as fuel or used as long-lived timber products. Where there are existing forests in good condition there is general agreement that they should not be cut for fuel and replanted. This principle also concurs with the guidelines for nature protection, that is, energy crops should never displace land uses of high ecological value. Where afforestation is undertaken, however, fossil fuel substitution, both by using wood fuel and using timber as a renewable raw material, should be more sustainable and less costly approach than sequestration could also be used to displace the harvest of more ecologically valuable forests.

Air pollution is becoming a great environmental concern in Sudan because the primary energy consumption increased. Air pollution from energy utilisation in the country is due to the combustion of petroleum, natural gas, wood, agricultural and animal wastes. The amounts of GHGs emissions are increasing quickly due to increasing energy consumption in the country (but lower than the other African countries).

In Some countries, a wide range of economic incentives and other measures are already helping to protect environment. These include: 1). Taxes and user charges that reflect the costs of using the environment e.g., pollution taxes and waste disposal charges. 2) Subsidies, credits and grants that encourage environmental protection. 3). Deposit-refund systems that prevent pollution on resource misuse and promote product reuse or recycling. 4). Financial enforcement incentives, e.g., fines for non-compliance with environmental regulations. 5). Tradable permits for activities that harm the environment.

Biomass and sustainability

There is an unmistakable link between energy and sustainable human development. Energy is not an end in itself, but an essential tool to facilitate social and economic activities. Thus, the lack of available energy services correlates closely with many challenges of sustainable development, such as poverty alleviation, the advancement of women, protection of the environment, and jobs creation. Emphasis on institution-building and enhanced policy dialogue is necessary to create the social, economic, and politically enabling conditions for a transition to a more sustainable future. On the other hand, biomass energy technologies are a promising option, with a potentially large impact for Sudan as with other developing countries, where the current levels of energy services are low. Biomass accounts for about one third of all energy in developing countries as a whole, and nearly 96% in some of least developed countries.

The convention on Biological Diversity set conservation of biodiversity on the world agenda. Gaps in knowledge need to be addressed for actions to be effective and sustainable. Gaps include: species diversity, microorganisms and their ecological roles, ecological and geographical status of species, human capacity to access and forecast bioecological degradation. Requirements for global inventories call for worldwide collaboration. Criteria for setting priorities need to be formulated and agreed. Global inventorying needs a collaborative international effort, perhaps under the aegis of the Convention on Biological Diversity. The recently formulated global taxonomy initiatives are a step in the right direction.

The debate over an international climate change regime has thus far focused primarily on efficiency concerns in developed countries. In the international negotiations over the control of climate change, the developing countries so far have assumed few obligations. In the Kyoto Protocol on limiting greenhouse gas (GHG) emissions, only a subset of the world's economies. At present, this debate has not progressed very far. There are several reasons for this impasse. First, there is a distinction between cost effectiveness (where in the world should the control be undertaken in order to minimize the global costs of control) and equity (who should bear the costs of mitigation and abatement resulting from climate change) that has not been adequately clarified and agreed upon by the parties to the Protocol. Second, the global control or anthropogenic climate change will require complex co-operative efforts among a large number of individual nations. This cooperative effort will have to be based on a thorough understanding of how the various participating nations contribute to the process of global climate change, and how that process affects them. One of the fundamental principles of environmental policy is that the polluter pays for using the environment and the use of natural resources. This is one way of imposing responsibility for environmental consequences on the party causing the environmental damage. In the context of environmental taxes, it is the polluter who pays, which is one reason why taxes are so suitable as an instrument for environmental policy. With respect to the causes of global warming, and the obligations, which were adopted at the Kyoto Conference, it is useful to examine the possible role of such economic instruments.

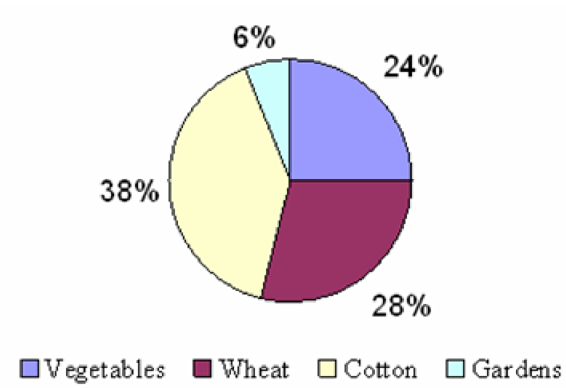
Sudan is an energy importing country and the energy requirements has been supplied through imports that have caused financial problems. Because of the economical problems in Sudan today, the Sudanese energy policy should be concentrated on assurance of energy supply: reliability, domestic sufficiency, in time, in economic terms, and renewability. Therefore as a renewable energy source, biomass (especially fuelwood) seems interesting because its share of the total energy production at 87% is high and the techniques for converting it to useful energy are easy. On the other hand, biomass may, however, see greatly expanded use in response to the environmental problems caused by fossil fuel use in the country. Biomass has been proposed to have a central role to play in future, more sustainable energy scenarios. For this to become a reality several real problems need to be overcome. In Sudan as in other developing countries modernisation of biomass energy provision is an urgent necessity for the sake of human health, protection of the environment, and climate change abatement. Given sufficient recognition, resources and research biomass could become the environmentally friendly fuel of the future. Even with modest assumptions about the availability of land, a comprehensive fuel-wood farming programme for Sudan offers significant energy, economic and environmental benefits. These benefits would be dispersed in rural areas where they are greatly needed and can serve as linkages for further rural economic development. The nation as a whole would benefit from savings in foreign exchange, improved energy security, and socio-economic improvements. With a nine-fold increase in forest – plantation cover, the nation's resource base would be greatly improved. The international community would benefit from pollution reduction, climate mitigation, and the increased trading opportunities that arise from new income sources. Sudan is an energy importing country and the energy requirements have been supplied through imports that have caused financial problems. Because of the economical problems in Sudan today, the Sudanese energy policy should be concentrated

Appendix Table 1A. Sustainability matrixes.

Power categories	1*	2*	3*	4*	5*	6*	7*	8*	9*	Index
Conventional coal fired stream plant	3	1	1	5	1	1	4	3	3	22
Oil fired stream plant	2	1	1	5	3	3	4	3	3	25
Combined cycle gas turbine	2	3	2	4	4	4	4	2	4	29
Micro combined heat and power	2	3	2	4	4	4	3	2	4	29
Nuclear	4	4	3	5	4	4	3	2	3	32
Hydropower	5	5	5	3	5	5	5	4	2	39
Tidal power	5	5	5	2	5	5	5	4	2	38
Onshore wind	5	5	5	2	5	5	4	4	3	38
Offshore wind	5	5	5	2	5	5	3	4	4	38
Land-fill gases	3	5	3	1	3	4	4	3	2	28
Municipal incineration	5	5	4	3	4	4	4	3	4	36
Biomass, field and forest crops Plus waste straw	5	5	4	3	4	4	4	3	4	36
Import	1	1	5	1	5	5	5	5	5	33
Hydro pumped storage	-	-	5	5	5	5	5	5	2	32
Electrochemical storage	-	-	4	4	4	4	4	4	5	29
Diesel	2	1	1	1	4	5	3	4	4	25

1* fuel availability. 2* price stability of fuel. 3* by-product acceptability. 4* grid services. 5* technological obsolescence. 6* knowledge base. 7* life of the installation. 8* maintenance requirement. 9* infrastructure requirements.

It is useful to codify all aspects of sustainability, thus ensuring that all factors are taken into account for each and every development proposal. Therefore, with the intention of promoting debate, a sustainability matrix is presented (Appendix 1A). The following considerations are proposed: (1) Long-term availability of the energy source or fuel. (2) Price stability of energy source or fuel. (3) Acceptability or otherwise of by-products of the generation process. (4) Grid services, particularly controllability of real and reactive power output. (5) Technological stability, likelihood of rapid technical obsolescence. (6) Knowledge base of applying the technology. (7) Life of the installation – a dam may last more than 100 years, but a gas turbine probably will not. (8) Maintenance requirement of the plant.



Appendix Figure 2A. Irrigated agriculture.

on assurance of Economic terms and renewability. There fore as a renewable energy source, biomass (especially fuelwood) Energy supply, reliability, domestic sufficiency, in time, seems interesting because its share of the total energy production at 87% is high and the technique for converting it to useful energy is easy. On the other hand, biomass may, however, see greatly expanded use in response to the environmental problems caused by fossil fuel use in the country. Biomass has been proposed to have a central role to play in future, more sustainable research biomass could become the environmentally friendly fuel of the future.

Conclusion

Sudan is an agricultural country with fertile land, plenty of water resources, livestock, forestry resources, and agricultural residues. Sudan energy showed the domination of biomass more than 80% and the household sector consumed more than 70% of the total energy scenarios. For this to become a reality several real problems need to be overcome. In Sudan as in other developing countries modernization of biomass energy provision is an urgent necessity for the sake of human health, protection of the environment, and climate change abatement. Given sufficient recognition, resources and biomass. Thus the Sudanese energy institutions adopted a strategy focusing on the promotion of conservation measures and introduction of alternative techniques such as direct briquetting and charring oil available agricultural residues and aquatic weeds. Water hyacinth (Eichhornia Crassipes Solms) is a free-floating aquatic plant, which causes much trouble for navigation in Sudan particularly along White Nile from Kosti up to Malakal (200,000 tons of wet water hyacinth annually). The water hyacinth as a wet substrate represents a promising candidate for bio-gas production by an aerobic fermentation and has been practiced since mid seventies in Sudan. In Sudan, there are currently over 200 installed biogas units, covering a wide range of scales appropriate to family, community, or industrial uses. The agricultural residues and animal was-tes are the main sources of feedstock for larger scale bio-gas plants. The production energy from agricultural bio-mass seems a realistic option for the future. Some solu-tions are technically feasible in short term. In some cases environmental, social and politic considerations justify their immediate exploitation even if economic evaluations of merely direct production costs do not justify at the mo-ment the investments necessary. Biomass is a renewable energy source, which can be converted into liquid fuels and/or gas fuels with different technologies available to-day. Ethanol production via fermentation, extraction and extractive-distillation is one such method and has been practiced for long time in most developing countries with agricultural surplus. However, intensive research and development activities are still needed.

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